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# Extreme mobility enhancement of two-dimensional electron gases at oxide interfaces via charge transfer induced modulation doping

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The discovery of two-dimensional electron gases (2DEGs) at the interface between two insulating complex oxides, such as LaAlO<sub>3</sub> (LAO) or gamma-Al<sub>2</sub>O<sub>3</sub> (GAO) epitaxially grown on SrTiO<sub>3</sub> (STO) [1,2], provides an opportunity for developing all-oxide electronic devices[3,4]. However, large enhancement of the interfacial electron mobility remains a major and long-standing challenge for fundamental as well as applied research of complex oxides. Here, with in mind the intrinsic electronic structure of the STO 2DEG[5], we inserted a single unit cell insulating layer of polar La<sub>1-x</sub>Sr<sub>x</sub>MnO<sub>3</sub> (x=0, 1/8, and 1/3) at the interface between disordered LaAlO<sub>3</sub> and crystalline SrTiO<sub>3</sub> created at room temperature. We find that the electron mobility of the interfacial 2DEG is enhanced by more than two orders of magnitude. Our in-situ and resonant x-ray spectroscopic in addition to transmission electron microscopy results indicate that the manganite layer undergoes unambiguous electronic reconstruction and leads to modulation doping of such atomically engineered complex oxide heterointerfaces. Moreover, the manganite spacer suppresses significantly the formation of oxygen vacancies on the STO side by preventing the interfacial redox reaction [6], which underlies the key to achieve the pure electronic reconstruction at the buffered interface. At low temperatures, the modulation-doped 2DEG exhibits clear Shubnikov-de Haas oscillations and the initial manifestation of the quantum Hall effect, demonstrating an unprecedented high-mobility and low electron density oxide 2DEG system. These findings open new avenues for oxide electronics.

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